A Clinical Data Repository Enhances Hospital Infection Control

Matthew Samore, M.D.
Deborah Lichtenberg, R.N.
Lisa Saubermann, R.P.H.
Catherine Kawachi, M.D.
Yehuda Carmeli, M.D.
Beth Israel Deaconess Medical Center/Harvard Medical School
Boston, Massachusetts

We describe the benefits of a relational database of hospital clinical data (Clinical Data Repository; CDR) for an infection control program. The CDR consists of >40 Sybase tables, and is directly accessible for ad hoc queries by members of the infection control unit who have been granted privileges for access by the Information Systems Department. The data elements and functional requirements most useful for surveillance of nosocomial infections, antibiotic use, and resistant organisms are characterized. Specific applications of the CDR are presented, including the use of automated definitions of nosocomial infection, graphical monitoring of resistant organisms with quality control limits, and prospective detection of inappropriate antibiotic use. Hospital surveillance and quality improvement activities are significantly benefited by the availability of a querable set of tables containing diverse clinical data.

INTRODUCTION

Surveillance of antibiotic resistance and nosocomial infections is one of the most important functions of a hospital infection control program (1). Historically, infection control surveillance has relied on ward rounds, reviews of medical charts and paper-based reports of microbiologic results. Analyses are typically conducted by assembling handwritten data or manually entering information into a computer database. These traditional infection control methods are time consuming and relatively inefficient for quantitative analyses and coping with the increasing complexity of antibiotic resistance. Furthermore, lack of standardization of methods and definitions impedes the ability to compare data across institutions. The potential value of computers for surveillance is widely recognized and recent reports have described effective computer applications for infection control (2-7). Nonetheless, a 1996 textbook on hospital epidemiology stated "the

effective and widespread use of computers in hospital epidemiology has proven to be a tantalizing but somewhat elusive goal for infection control practitioners since the late 1970s" (8).

At the Beth Israel Deaconess Medical Center (BIDMC), West Campus, a relational database referred to as the Clinical Data Repository (CDR) was developed to store current and historical clinical data. Certain members of the infection control unit were granted privileges to construct ad hoc queries, thus creating an opportunity to enhance the effectiveness of infection control surveillance. We present examples of the use of the CDR to automate definitions of nosocomial infection, graphically display the occurrence of resistant organisms with quality control limits, and prospectively monitor appropriateness of antibiotic use.

METHODS

Institutional Environment

BIDMC was formed from the merger of two academic, tertiary referral institutions, Beth Israel Hospital and Deaconess Hospital. The CDR of the BIDMC-West Campus (Deaconess Hospital) was built by integrating multiple legacy data sources into a set of Structured Query Language (SQL) compliant Sybase tables residing on a Hewlett-Packard 9000 server. Most of the CDR development work was completed by 1995. The main body of the CDR currently consists of 47 tables. The largest table, which contains laboratory test results, currently has greater than 13 million rows. Some tables, such as laboratory results and medications, are updated on a real-time basis, whereas other tables are updated daily in a batch mode. Historical information ranges back to 1991 to 1993, depending on the data type. A security policy controlling access to the CDR was

developed and administered by a governing body of physician and Information Systems Department leaders.

Content of the CDR

The CDR contains inpatient and outpatient clinical laboratory results, inpatient medications, inpatient and outpatient radiologic tests, ICD9 codes for inpatient diagnoses/procedures, admit/discharge dates, DRGs, nursing acuity scores, demographic information, discharge summaries, EKG findings, as well as a large number of data elements extracted from the CareVue ICU system. The room location of each patient for each hospital day is stored. Culture results from the clinical microbiology laboratory are housed in two different tables. One table consists of one record for each culture and contains information on the culture type, such as source and test name. The other microbiologic table consists of one record for each antibiotic sensitivity of each isolate or, for isolates without antibiotic susceptibilities, one record for each isolate. This table contains the organism name.

Infection Control Surveillance Functions

The purpose of infection control surveillance is to detect problem areas, track temporal trends, and institute successful control measures. Bloodstream infections (bacteremias) and surgical wound infections constitute two important classes of infections because of their associated morbidity, mortality, and cost. Antibiotic-resistant pathogens, such as vancomycin-resistant enterococci and multi-drug resistant *Pseudomonas aeruginosa*, are significant because of the difficulties they pose for treatment and their ability to spread between patients.

CDR Applications: Primary Design Features

Applications of the CDR were developed via Microsoft Access 2.0 (MS Access) using the Open Database Connectivity (ODBC) Driver to attach and query CDR tables. Queries, forms, and reports for surveillance functions were constructed and executed by members of the infection control unit; none of the applications relied on knowledge of programming code. Multiple tables were easily joined within MS Access queries by using the mouse pointer to connect key fields. Because of extensive indexing, even complicated queries had acceptable

performance times (typically 3 to 30 seconds). In general, the CDR was employed to populate and update local Access tables corresponding to each major infection or organism category. For certain types of infection, clinical data elements not directly available from the CDR were manually added to the MS Access tables. Conversely, the local Access tables were frequently linked back to the CDR to retrieve additional data elements, either as part of a routine function or on an ad hoc basis as the need arose. The sequential queries needed to generate or update local tables, perform calculations, and produce reports were organized into macros to increase ease of use. Applications which fulfilled an ongoing surveillance need were executed on a routine schedule. Since these applications were assembled by the infection control unit, modifications in the system over time did not require technical support from Information Systems.

CDR Applications: Specific Examples

Tracking of Resistant Organisms. Prior to the availability of the CDR, information on patients with resistant organisms was stored primarily on handwritten lists, which tended to be incomplete and difficult to analyze quantitatively. Soon after the CDR was developed, MS Access queries and macros were constructed to track ten different types of nosocomial resistant organisms: methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant enterococci, *Clostridium difficile*, extended-spectrum beta-lactamase producing *Klebsiella sp.*, imipenem-resistant Enterobacteriaceae, imipenem-resistant *P. aeruginosa*, ceftazidime-resistant Enterobacteriacea, ceftazidime-resistant *P. aeruginosa*, ciprofloxacin-resistant gram negative rods, and gram negative rods resistant to both tobramycin and gentamicin. Resistant organisms were classified as nosocomially- or community-acquired based on the timing of culture isolation relative to hospitalization and on the history of previous hospitalizations. Additional queries were developed to analyze the history of room locations and attending physician services for each patient to assess the ward of acquisition and identify epidemiologic links between patients with the same type of resistant organism. Graphs with quality control limits (9) were devised using the graphic capabilities of MS Access and, in selected instances, SAS for Windows, 6.11.

Automated Surveillance Definition Of Bacteremia. For certain organisms which commonly colonize the skin, such as coagulase negative staphylococci, differentiation between "true" bacteremia and contamination has traditionally relied on clinical criteria, such as presence of fever or an intravascular device. A simplified surveillance definition of "true" bacteremia based on microbiologic criteria alone has the advantage of reducing time spent in chart review and may be easier to standardize across institutions. In a recent multi-institutional study, such a definition was evaluated, using the following criteria for "true" bacteremia: isolation of a pathogen-type organism from one or more blood cultures or isolation of a common skin contaminant organism of the same species from two or more blood culture sets obtained within 5 days (10). A representative sample of 149 positive blood cultures from 7 different institutions were evaluated in this study. The agreement rate between the two definitions of bacteremia was high.

Subsequently, we developed MS Access queries to apply the simplified microbiologic definition of bacteremia to blood culture results downloaded from the CDR. Rates of bacteremia during a one year period (January to December, 1996) based on the traditional and simplified surveillance definitions were calculated and compared.

Monitoring Of Vancomycin Use. Intensive use of antibiotics in hospitals contributes to the problem of antibiotic resistance due to selection pressure. Thus, an important intervention to help control spread of vancomycin-resistant enterococci is to reduce use of vancomycin. According to guidelines published by the Centers for Disease Control (CDC), the primary indication for vancomycin use is to treat infections due to gram positive organisms resistant to beta-lactam antibiotics or to treat gram positive infections in patients who have a significant beta-lactam allergy. In 1995, we used the CDR to evaluate appropriateness of vancomycin use by linking data from medication and microbiology tables and found that a significant proportion of patients did not appear to meet CDC criteria for prudent vancomycin use. Therefore, we instituted an intervention which targeted patients on vancomycin for more than two days. An MS Access macro was developed to download currently hospitalized patients on parenteral vancomycin, along with their culture results. Physicians of patients whose vancomycin use was not supported on the basis of microbiologic cultures were contacted by the infectious disease pharmacist. Unless adequate justification for further use was provided, a strong recommendation was issued to discontinue vancomycin. Aggregate queries on the medication table, linked to admit and discharge dates to denominate by patient days, were constructed in order to track the volume of vancomycin use before and after the intervention.

RESULTS

Detection Of Clusters Of Resistant Organisms

We have found that each year 800 to 900 microbiologic isolates from 400 to 500 patients belong to one of the resistant organism categories (out of a total of 18,000 to 20,000 isolates per year). This greatly exceeds the number of isolates and patients that can be effectively tracked using a manual system. One of the benefits of closer surveillance of patients with these organisms has been more rapid detection of temporospatial clusters. An example of such an event is demonstrated in figure 1, which shows the number of patients with imipenem-resistant *P. aeruginosa* per week. The small cluster occurred during a 4 week period from September to October, 1996 and would have been missed without use of the computerized analyses. An investigation revealed that the cluster actually represented false-resistance due to defective antibiotic susceptibility panels (11). This finding led to changes in susceptibility testing procedures in the clinical microbiology laboratory.

Automated Surveillance Definition Of Bacteremia

Monthly rates of nosocomial bacteremias (number of bacteremic episodes divided by the number of patient-days) were determined using the simplified bacteremia definition and traditional clinical definition. The rationale for comparing monthly rates was that data in reports for the Infection Control Committee are aggregated by month. The monthly bacteremia rate by the two methods was identical during 5 of 12 months; the maximum difference in number of nosocomial bacteremias during a single month was 4. The relative difference in bacteremia rate summed over the entire year period was less than 2%. We concluded that the different bacteremia surveillance definitions gave highly compatible results and have

now formally adopted the simplified bacteremia definition into our surveillance plan to improve standardization across both campuses of our merged institution.

Monitoring Of Vancomycin Use

In 1996, the average census of patients on parenteral vancomycin was 14. The infectious disease pharmacist made an average of two pages or calls per day to physicians because of lack of microbiologic justification for continued vancomycin use. Following institution of this plan, vancomycin use, as gauged by antibiotic-days per 100 patient-days, declined by 20%. Thus, the intervention was at least moderately successful, but was relatively time-consuming for the infectious disease pharmacist. We believe that automated methods of communication and decision support at the level of physician order entry are likely to be both more effective and more efficient.

DISCUSSION

In this paper we describe the data elements and functional requirements of a hospital CDR that proved most useful for an infection control program. The key features of the CDR which enhanced its utility were: 1) the ease and flexibility with which the user could interactively link multiple types of clinical information and design ad hoc queries; and 2) its accessibility to individuals outside of Information Systems who had expertise within the domain of infection control and experience with relational databases, but did not have knowledge of programming code. MS Access proved to be an inexpensive, user-friendly front end tool that fostered data integration and permitted a wide range of queries of varying complexity. Using information directly from the repository increased data accuracy because of decreased reliance on manual data entry and handwritten lists. The CDR tables and data elements most frequently used for infection control applications were microbiologic culture results, medications including start and stop dates, and epidemiologic details such as ward locations, attending physician services, and admit and discharge dates.

We present examples of specific applications that illustrate the advantages of the CDR for detection of clusters of resistant organisms, surveillance of bacteremia, and monitoring of vancomycin use. Additional applications have been

developed which follow similar principles. Limitations of the present CDR include the lack of certain data types such as progress notes, vital signs of non-ICU patients, outpatient medications, and outpatient problem lists.

In summary, we find that the CDR permits infection control data to be analyzed more efficiently and comprehensively, with less work expenditure, and in a more timely manner than traditional methods. Inter-institutional comparisons and quality measurements are becoming increasingly important within the healthcare industry. Thus, the value of the CDR for hospital surveillance and infection control will continue to rise as the need for comparable and accurate data increases.

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Figure 1. Statistical process control graph ["c chart" (9)] of number of patients with imipenem-resistant *P. aeruginosa* per week, demonstrating a cluster of cases in September, 1996 exceeding the upper control limit. The graph was created in SAS for Windows 6.11 using the quality improvement module. An MS Access table generated from the CDR was imported into SAS using dynamic data exchange (DDE).

ORGNAME=PSEUDOMONAS AERUGINOSA ANTIBIOTIC=IMIPENEM
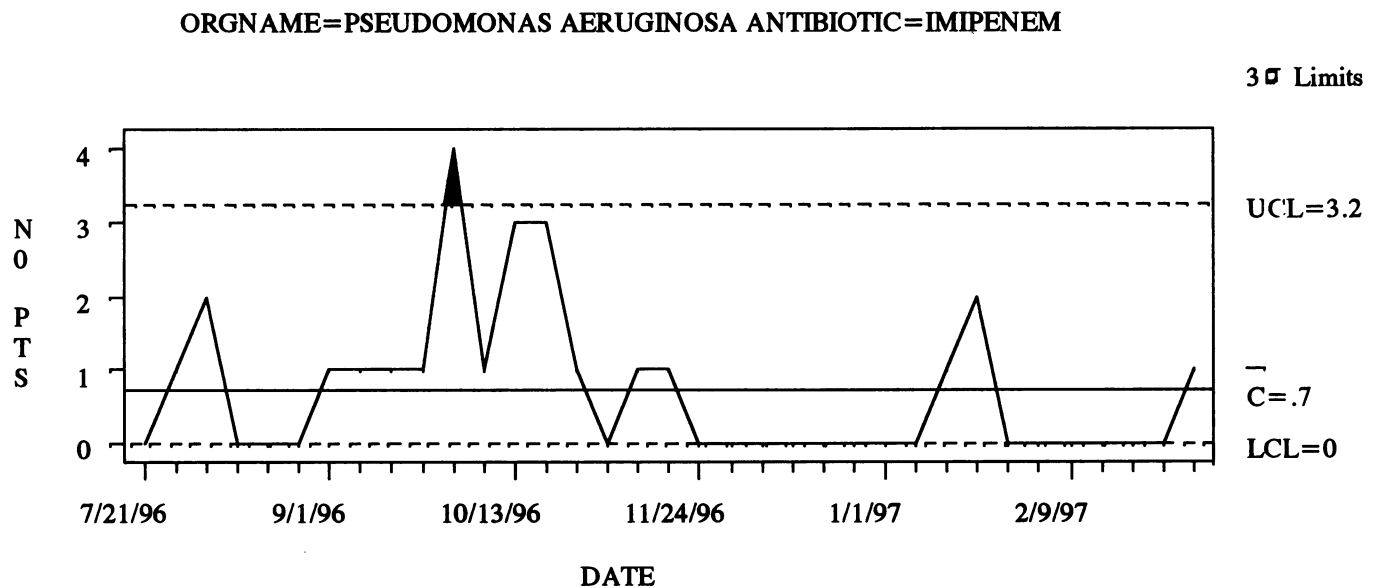
Legend: $\overline{C}$: mean; LCL: lower control limit; UCL: upper control limit (3 standard deviations greater than the mean).